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Simulation and Experimentation Study of Mass Flow Rate in The Vortex Flow Metre

Nur Adlina Juzly[1], **Rohani Rahmad**[2]*

[1]Department of Mechanical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Muar, Johor, MALAYSIA

[2]Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Muar, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Flow metres of the vortex type are used to measure the velocity of the flow of gases and liquids in a specific container, such as a pipeline, a tank, a chamber used in industry, or a natural source. Each has its own technology and way of working. Currently, the Vortex Flow Metre in UTHM employs a model Digital YEWFLO 040 with suffix codes DBLSS1-2D to measure the flow rate of pipeline steam starting at one bar and not exceeding five bars produced by the boiler operation. This study aims to simulate the Vortex Flow Metre model with a steam pipeline from 100 kPa to 500 kPa. The realistic geometry of the model was applied using the Solidworks software, which was used to produce the 3D modelling of the steam pipe with the Vortex Flow Metre. Meshes were made and a boundary condition was added to the model with the help of ANSYS Workbench software. In this study, there was also an experimental method used to get the actual mass flow rate data from the Vortex Flow Meter. The results of both the simulation and the experiment were compared and figured out. The results of the simulation show that as the pressure went up, so did the mass flow rate and this shows that the relationship between pressure and flow is linear. The mass flow rate is greater in the simulation value than in the experiment. In the experiment, the steam pressure was controlled by the temperature relief valve in manual mode when the pressure gauge reached 3 to 5 bars. The heating process in the Biodiesel Pilot Plant at UTHM requires a certain amount of pressure to be applied and maintained. The difference between the simulation and experiment flow rate values is almost the same, which is ±20%. According to the findings of this study ±20% is an acceptable range, also it is important to keep track of the mass flow rate data in order to enhance and improve the efficiency of steam itself.

Keywords: Vortex Flow Metre, Mass Flow Rate, Simulation Analysis, Experimental Work

Corresponding author: rohani@uthm.edu.my

1. Introduction

A Vortex Type Flow Metre is a velocity type flow metre that has a tendency to have a linear connection with the volume and mass flow rate when the flow rate is increased. Flow metres of the vortex type are flow measurement devices that are used to measure the flow velocity of gases and liquids in situations [1] It is to calibrate, decide on, and analyses the appropriate volume or flow of liquid in a given situation. It also aids in the advancement of efficient liquid management by identifying instances of abuse or leakage that result in wasting of liquid. It is important to understand flow measurement in this context since steam is commonly employed as a source of energy generation in the production of plant and electricity [2].

The Vortex Flow Metre is an instrument that operates on the idea that vortices shed behind a body put in the flow. A. Venugopal et al. state that, the vortex shedder with pipe assembly and sensor is the main component. The vortex shedder is the center of the flowmeter. The form, blockage, and other geometrical characteristics of the vortex shedder determine the strength, linearity, and stability of the vortex. The major factor affecting a flowmeter's rangeability is the vortex shedder [3] It is investigated that many bluff bodies with sharp edges, including cylinders, rectangles, trapezoids, and T-shaped bodies [4]

The usage of a Vortex Flow Metre, which is generally used for measuring steam mass flow rate at the UTHM Biodiesel Pilot Plant, was examined in this current study. Before conducting the experiment, the P&ID drawing was redrawn to better understand the flow of steam produced by the boiler. The simulations in ANSYS Workbench software were conducted by using the model of Vortex Flow Metre with steam pipeline, to evaluate and generate the mass flow rate value. For experiment work, the pressure was applied from one bar to five bars to get the mass flow rate value on Vortex Flow Metre itself. Significant comparison between experiment and simulation can be made clearly and determined.

2. Methodology

The selection of a Vortex Flow Metre is very important in order to design the structure in SolidWorks software. For this study, a digital YEWFLO model DY040 was chosen to serve as the Vortex Flow Metre. It is generating the mass flow rate of steam from the boiler and was transferred to the Biodiesel Pilot Plant. The design specifications of the Vortex Flow Metre were written out in Table 1.

Table 1: Vortex Flow Metre specification

Model No.	Suffix Code	Output Signal	Body Material	Shedder Bar Material	Process Connection	Indicator
DY040	DBLAA1-2D	D - 4 to 20mA DC, Pulse BRAIN Communication	B - CF8M*5	L - Duplex Stainless Steel	AA1 – ANSI Class 150 Wafer	With indicator

2.1 3D Modelling of Pressure Vessel

For beginning, a 3D volute Vortex Flow Metre model was created in Solidworks software to simulate the data for ANSYS Workbench software. Solidworks was a 3D modelling software that allowed users to create fully solid models for both design and simulation. At the initial stage of developing the body and shedder bar, as shown in Figure 1.

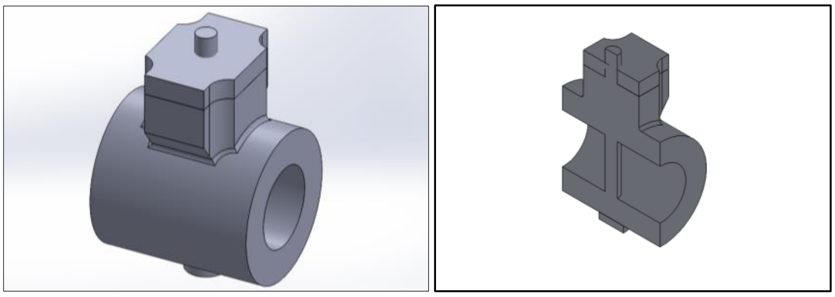

Figure 1: 3D model and Shedder Bar of Vortex Flow Metre

2.1.1 Material Properties of Vortex Flow Metre

The body of Vortex Flow Metre was made of stainless steel. Table 2 shows a mechanical property of stainless steel according to national codes and standards published by the American National Standards Institute (ANSI) and ASTM

Table 2: The Material Properties of Vortex Flow Metre

Property	Value	Units
Elastic Modulus	1.9×10^{11}	N/m^2
Poisson's Ratio	0.3	N/A
Tensile Strength	550000001.7	N/m^2
Yield Strength	137895145.9	N/m^2
Mass Density	8000.000	Kg/m^3

2.1.2 Pipe structure Design

In order to replicate the data for ANSYS Fluid, a 3D volute steam piping was constructed in Solidworks to simulate the data based on Figure 2. Steam pipe dimensions are expressed in millimeters; they are combined with the Vortex Flow Metre and assigned the Solid type.

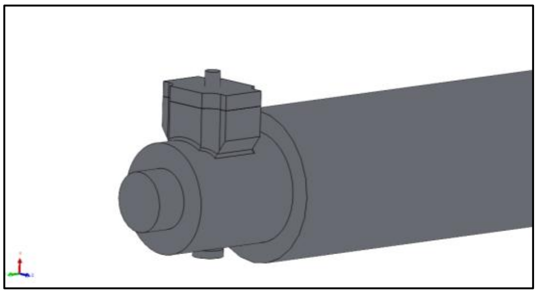

Figure 2: Design of Steam Piping Combine with VFM

2.2 Mesh Generation

The development of a mesh or grid is an essential component of the process of engineering simulation, which involves breaking down complicated geometries into more manageable parts. The Vortex Flow Metre used the standard type mesh or fine types based on Table 3. As Figure 3 shows, the meshing takes up a substantial percentage of the time required to force the simulation results. The solution is both quicker and more accurate if the tools used for meshing are of better quality and have a greater degree of automation. Insert the name of the steam pipe's intake, was chosen where the pressure was applied, and output, where the steam pressure will flow out, and last step was generating the mesh. The element size and tolerance number are 25 millimetres.

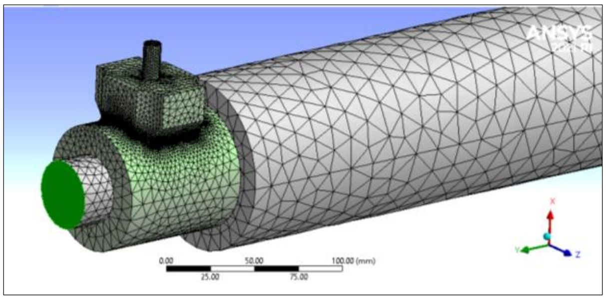

Figure 3: Meshing Part of the Solid Domain

Table 3: Characteristics of The Meshing Parts

Mesh Type	Solid mesh
Mesh Used	Standard Mesh
Elements Size	25.00 mm
Mesh Quality	Medium
Total Nodes	284106
Total Elements	1332833

2.3 Set Up the Properties

This simulation used the steam pressure or water vapour that flows through the Biodiesel Pilot Plant's pipe system. Created water vapour as the substance with the density of 0.5542 and the viscosity of $1.34e^{-0.5}$. As there are two models used, set the steam pipe to the water vapour type and the Vortex Flow Metre to the solid type. Next, for the input boundary conditions are 100 kPa (1 bar) and the outflow boundary conditions are 0 kPa (atmospheric pressure). Experiment data was collected from Vortex Flow Metres then the data was used to calculate the mass flow rate on the outflow surface that show in figure 4. In the surface report, which is mass flow rate, will be chosen as the report definition on the outlet surface.

```
Calculation complete.

     mass-flow-rate
 -------------------
                   Mass Flow Rate              [kg/s]
-------------------------------- --------------------
                          outlet        -0.057751482
```

Figure 4: The Mass Flow Rate Data

2.4 Design of Experiment

Before starting up the boiler, a few more utilities, such as the cooling tower, compressor, and boiler, must be checked and some chemicals added to maintain the plant's quality. In the first phase of the process, the cooling tower needs to have its water quality examined, and chemicals are added to the basin based on their quantity for the cooling tower.

The oil level in the storage tank for the compressor must be drained until all of the water in the tank evaporates, and then more oil must be added to maintain a constant level of oil in the tank. Lastly, the boiler may finally be started up and put into operation after adding some chemicals to treat the water.

The fire tube boiler is the kind of boiler that has been used in the pilot plant for biodiesel production at UTHM to supply steam to the Biodiesel Pilot Plant.

Table 4: List of Chemicals

Utilities	Type of chemicals	Volume
Cooling tower	BP 653 (Non- Oxidizing Biocide)	1.5 Litre
Boiler	BP 100 (Oxygen Scavenger)	1.5 Litre
	BL 802 (All in one Multi-Purpose Boiler Chemical)	2.0 Litre
	BL 210 (pH and Alkalinity Booster)	2.0 Litre

2.5 Reading of Vortex Flow Metre

According to the Figure 5, to read the Vortex Flow Meter, take the value of the mass flow rate from the metre itself; the value kilogram per hour (Kg/h) is above the total kilogram (Kg). The number of kilograms in a metre will be used to classify the amount of steam going through the pipe during all activities.

Figure 5: Metre Reading

3. Results and Discussion

This part shows the result of mass flow rate obtained from the simulation and experimental work. In the simulation, the finite element analysis was carried out by using ANSYS Workbench of fluid flow (fluent) analysis. The model of steam pipe with Vortex Flow Metre as followed by their density, 0.5542 kg/m3, the thermal conductivity, 0.0261 W/mk and viscosity is 1.34e-05. The initial inlet pressure is from 100 kPa to 500 kPa was used to get the final output which is mass flow rate for this study.

For the experiment, the boiler produced steam from one bar to five bars and read the mass flow rate at the Vortex Flow Metre itself. Both sets of data were compared to analyze the heat loss from the two methods.

The P&ID drawing was redrawn based on the purpose to better comprehend the path of pipeline steam from the tank reservoir to the Vortex Flow Metre. the P&ID drawing was employed as a reference and comparison for creating the 3D pipeline steam in Solidwork software.

3.1 Fluent Analysis of Vortex Flow Metre

The steam pipe with Vortex Flow Metre was analysed by using a fluent analysis system with five different pressure values. The analysis focused on the mass flow rate that flow through the pipe at the inlet of pipe. Some velocity streamlines are also included in this chapter in order to examine the steam pressure flow via the pipe and the Vortex Flow Meter.

Table 5: Simulation Result

Pressure (kPa)	Mass Flow Rate (Kg/s)	Mass Flow Rate (Kg/h)
100	0.0577	205.02
200	0.0761	273.60
300	0.0769	276.84
400	0.0833	296.53
500	0.0859	309.10

Simulation results shows that as pressure increased, the flow rate also increased. Results show that there is linear relationship between pressure flow, thus agreed with Akresh, M. et al. findings [1]

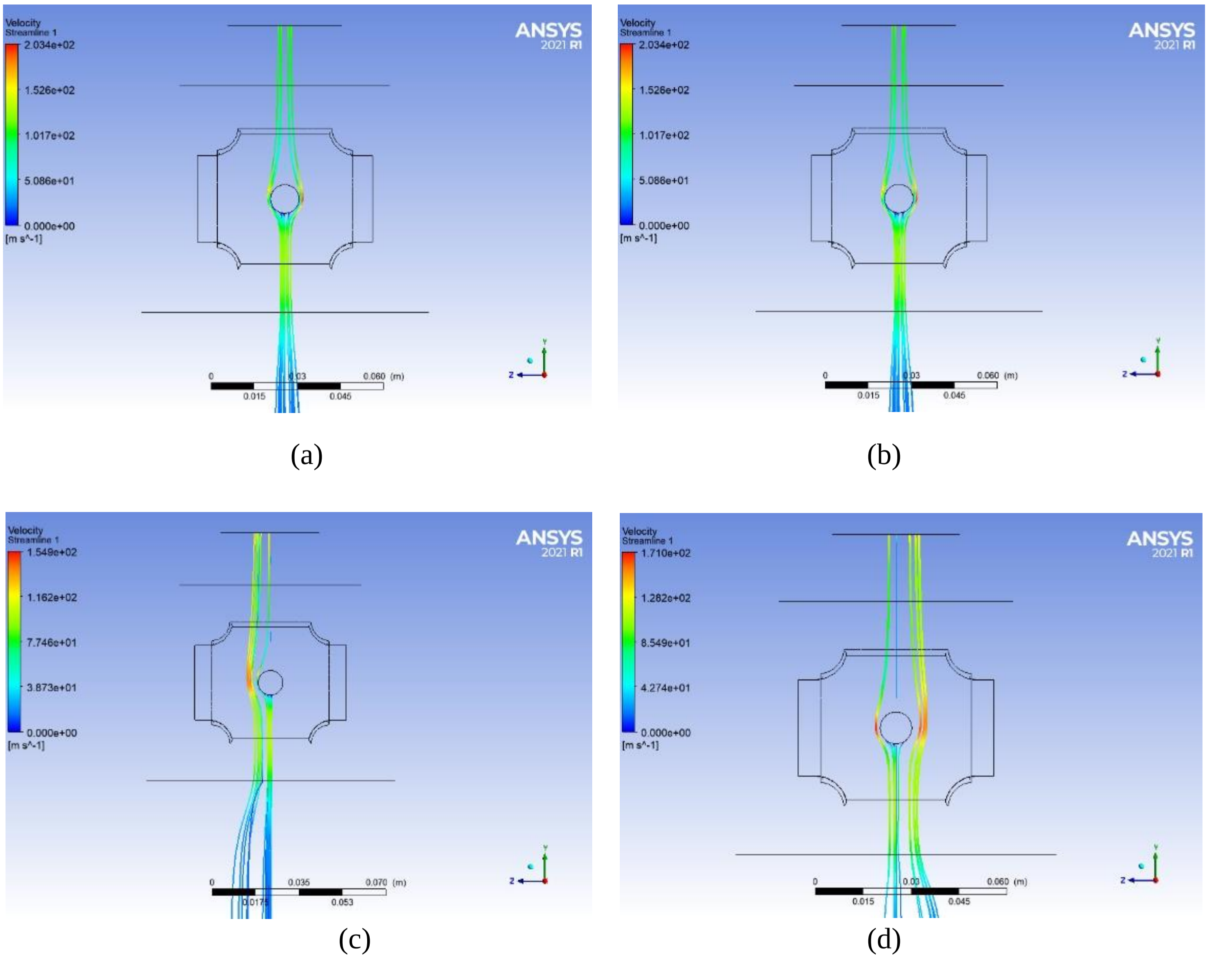

Figure 6: The Streamline of Velocity Contour. (a) Pressure=200 kPa, (b) Pressure=300 kPa, (c) Pressure=400 kPa, (d) Pressure=500 kPa.

From the Figure 6, for low pressure which is 100 kPa the velocity has the maximum value after pressure flow through the Vortex Flow Metre and not happened on shedder bar of Vortex Flow Metre. The pressure continues to rise from 200 kPa to 500 kPa as the mass flow rate continues to increase. When the steam pressure passes over the shedder bar of the Vortex Flow Meter, the resultant streamline reveals some turbulence. Since vortex metres detect the frequency of vortices formed by a "bluff body" or "shedder bar,". On the shedder bar side where the vortex is forming, the fluid velocity is greater and the pressure is lower. According to the visual on Figure 5 provided by the simulation, the colour red represents a greater velocity value.

According to Figure 6(a), the values of the mass flow rate are increasing and are close to the values at 100 kPa pressure. Maximum streamline velocity occurred when steam pressure flowed to the right of the shedder bar, and minimum streamline velocity occurred after flow through the Vortex Flow Meter, as seen in figure 6(b). At 400 kPa, the mass flow rate is 296,53 kg/s, which is shown in Figure 6(c) as a streamline flow through the metre on a single side, resulting in an extremely high velocity reading. For a final pressure of 500 kPa, the streamline flow through the vortex flow metre has maximum velocity on both sides.

3.2 Experiment Data

Before running the boiler and allowing steam to flow through the pipe, the technician had calibrated the Vortex Flow Metre according to the laboratory standard. This is to ensure the flow rate reading was accurate. Table 6 displays the actual value of the vortex flow metre at UTHM's Biodiesel Pilot Plant. From 1 to 3 bar of pressure, the mass flow rate gradually increases from 240 kg/hr to 254 kg/hr. From two to five bars, the meter's value decreases, and the value maintain which is 250 kg/h to reach five bars.

Table 6: The Mass Flow Rate

Pressure (Bar)	Mass flow rate (Kg/h)
1	240
2	251
3	254
4	252
5	250

3.3 Comparison of Simulation and Experiment Data

According to both results from graph in Figure 7, the simulation value has a higher mass flow rate than the experiment value. This is because the steam pressure was regulated by the temperature relief valve in manual mode when the pressure gauge reached 3 to 5 bar in the experiment. In the plant process, the heating process has a certain pressure to employ and maintain

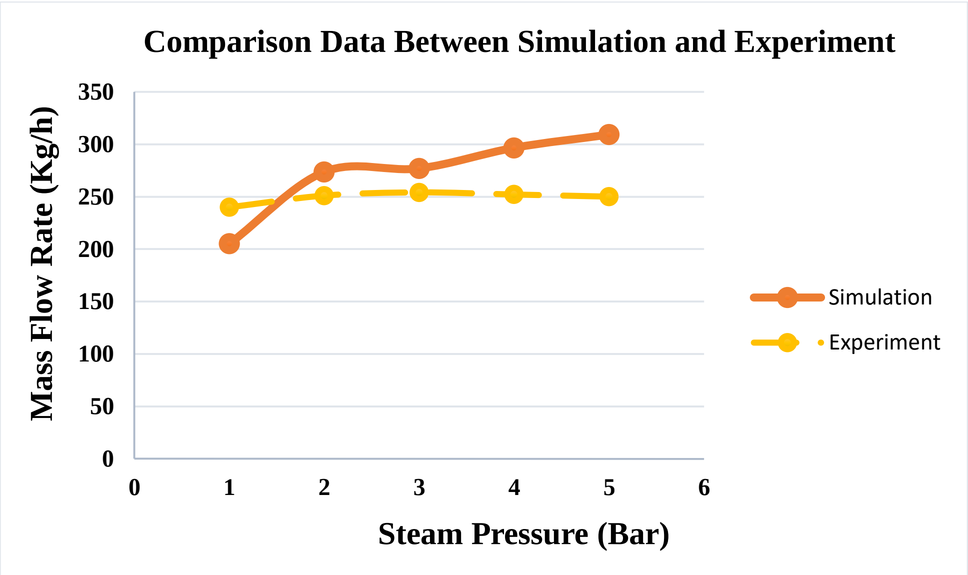

Figure 7: Comparison Graph between Simulation and Experiment

In Table 7, the percentage difference between the two values has a greater value on the 5 Bar of pressure, which is 21.14%. The percentage is the same for the two and three bars, coming in at 8.61% and 8.60% respectively. For 4 bar the percentage difference between experiment and simulation is 16.24%. It shows that the difference between simulation and experiment flow rate values is almost the same which is ±20%.

Table 7: Comparison Data of Simulation and Experiment

Pressure (kPa)	Pressure (Bar)	Mass Flow Rate (Kg/h) in experiment	Mass Flow Rate (Kg/h) in simulation	Percentage Difference (%)
100	1	240	205.02	-15.23
200	2	251	273.60	8.61
300	3	254	276.84	8.60
400	4	252	296.53	16.24
500	5	250	309.10	21.14

4. Conclusion

It may be concluded that this study has fulfilled the objectives. The first objective was to simulate a computational model of the flow rate from boiler piping to Vortex Flow Metre using ANSYS Workbench Software. The 3D modelling of the Vortex Flow Metre has been modelled in the Solidworks software first before imported to the ANSYS Workbench software. The second objective is to determine the actual value of flow rate on Vortex Flow Metre at Biodiesel Pilot Plant by performing the experiment. The VFM dimension is based on YEWFLO Vortex Flow Metre specification to complete this simulation analysis. Last objective was to compare both data from simulation and experimental work to check the heat loss happened on pipeline of steam with Vortex Flow Metre.

When the pressure difference was applied, the simulation data shows a larger value of mass flow rate. From 200 kPa to 300 kPa, the value of mass flow rate increases steadily. When the pressure reaches 500 kPa, the mass flow rate value is greater than the experiment between 250 and 309.10 kg/h. In the experiment, the pressure was monitored for the plant process and the data began with an increase and gradually decreased. If the pressure was not controlled, it may disrupt the operation and cause the pipe to rupture. Both simulation and experiment produce same value of flow rate difference in ±20%.

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References

[1] Akresh, M., Reindl, L., & Vasic, M. (2010). Extended Measurement Range of Vortex Flow Meter in High Turbulent Range.

[2] T.L. Brown, (2016) Steam quality measuring apparatus and method, US Patent 3,392,572. Retrieved from https://www.lens.org/lens/patent/US_3392572_A.

[3] Venugopal, A., Agrawal, A., & Prabhu, S. (2019). On the linearity, turndown ratio and shape of the bluff body for vortex flowmeter. *Measurement*, *137*, 477–483

[4] El Wahed, A. K., Johnson, M. W., & Sproston, J. L. (2019). Numerical study of vortex shedding from different shaped bluff bodies. Flow Measurement and Instrumentation, 4(4), 233-240.